ORIGINAL

NATIONAL UNIVERSITY OF SINGAPORE

EXAMINATION FOR

(Semester I : 2017/2018)

EE5703 – INDUSTRIAL DRIVES

Nov 2017 – Time Allowed: 2 Hours

INSTRUCTIONS TO CANDIDATES

1. This paper contains **SEVEN (7)** questions and comprises **FIVE (5)** printed pages.
2. Answer **ALL** questions.
3. Total marks for the paper is **60**.
4. This is a **CLOSED BOOK** examination.
5. Programmable calculators are allowed.

Q.1 Answer the following multiple choice questions. For each question only one choice is correct among the four choices. Each question carries ½ marks.

(5 marks)

a) Which of the following theory is not used for a typical motor drive system?
   i. Machine theory
   ii. Control theory
   iii. Wireless theory
   iv. Power Electronics theory

b) Which of the following is not a typical benefit for the electric drive system EHM (equipment health monitoring)?
   i. Improved reliability and availability
   ii. Increased efficiency of the electrical machine
   iii. Optimized maintenance planning for the electric drive
   iv. Minimized unplanned downtime and reduced risk levels

c) Which of the following is false about permanent magnet DC (PMDC) motor?
   i. Magnets are on the stator
   ii. Windings are on the rotor
   iii. Two DC sources are required
   iv. No input power is consumed for the excitation

d) Which of the following is false for the torque speed characteristics of a DC motor?
   i. Motor is mostly operated at rated torque above the base speed
   ii. Motor is mostly operated at rated power above the base speed
   iii. Field flux drops above the base speed
   iv. Armature voltage is constant above the base speed

e) Which of the following is true about the saturation of switched reluctance motor?
   i. Motor operates linearly in deep saturation region
   ii. Operation in saturation has no impact on utilization factor of the motor
   iii. Operation in saturation reduces the utilization factor of the motor
   iv. Operation in saturation increases the utilization factor of the motor

f) Direction of rotation can be reversed for a switched reluctance motor (SRM) by
   i. Changing the direction of current
   ii. Changing the sequence of stator excitation
   iii. Stop switching the power converter
   iv. None of the above

g) Which of the following is false about the power converters used for the SRM?
   i. Power converters are always required for the operation of SRM
   ii. Power converters are sometimes required for the operation of SRM
   iii. There are several kinds of power converters based on phase switches
   iv. There are several kinds of power converters based on commutation type

h) What are the numbers of switching sequences for a typical brushless DC motor?
   i. 2
   ii. 4
   iii. 6
   iv. 8

i) Which of the following is true for the currents in a brushless DC (BLDC) and permanent magnet synchronous motor (PMSM)?
   i. Currents are triangular for BLDC and square for PMSM motor
   ii. Currents are square for BLDC and triangular for PMSM motor
   iii. Currents are sinusoidal for BLDC and square for PMSM motor
   iv. Currents are square for BLDC and sinusoidal for PMSM motor

j) Which of the following is false about the permanent magnet (PM) motors?
   i. Surface PM motor usually have a rotor banding
   ii. Material properties play a crucial role in the selection of magnets
   iii. Magnetic properties also depend on the operating temperature
   iv. Interior PM rotor always has a unique way of placing magnets inside rotor

Q.2 (a) A 200 V, 2000 rpm shunt DC motor has the armature and field resistance of 0.5 Ω and 400 Ω respectively. The rated armature current I_a= 10.5 A. It drives a load whose torque is constant at the rated motor torque. Calculate motor speed if the source voltage drops to 175 V.

(3 marks)

Q.2 (b) A 220 V, 1500 rpm, 50 A separately excited DC motor has an armature resistance of 0.5 Ω. It is fed from a three-phase fully controlled rectifier. The motor is fed from a circulating current dual-converter with an AC source line voltage of 165 V. Determine the converter firing angles for the following operating points
(i) motoring operation at rated motor torque and 1000 rpm,
(ii) braking operation at rated motor torque and -1000 rpm.

(4 marks)

Q.2 (c) Fig. Q.2(c) shows a four quadrant chopper feeding to a DC motor. Mention the power switches and diodes which support the current flow in each of the four quadrants.

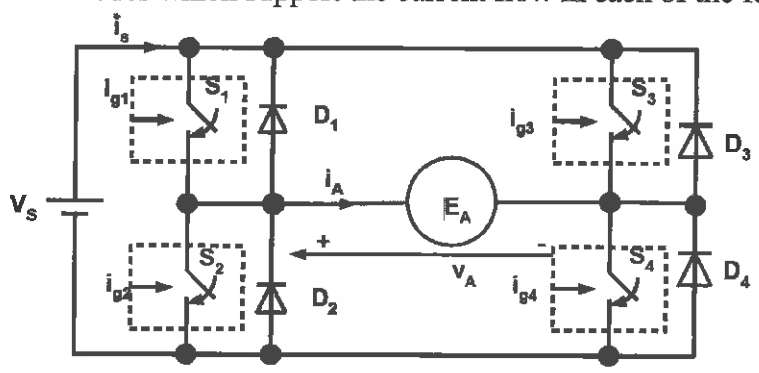

Fig. Q.2(c)

(2 marks)

Q.3 (a) Briefly describe the torque control method for a switched reluctance motor (SRM) using the angle control during the motoring mode. Draw torque speed characteristics for a SRM and highlight the region in which angle control is used?

(3 marks)

Q.3 (b) Comment on the need of rotor position sensing for a switched reluctance motor (SRM). Briefly describe direct and indirect rotor position sensing methods.

(3 marks)

Q.4 (a) What is the importance of 'BH_{max}' on the BH curve of a given magnetic material?

(2 marks)

Q.4 (b) What is the main source of torque ripples in a brushless DC (BLDC) motor?

(2 marks)

Q.4 (c) Write two key differences between a brushed versus a brushless DC motor.

(1 marks)

Q.5 Write a short article on any real life motor drive application known to you. Draw the electrical schematic of this drive? Please include comments on the following.

- The type of electric motor and power converter used in the drive,
- The four quadrant operation (if applicable) of the drive including any braking,
- Mention different characteristics of your drive including merits and demerits, and
- Mention need for any equipment health monitoring (EHM) for this drive.

(5 marks)

Q.6 (a) A 3-phase AC machine is supplied from a balanced 3-phase, 415V($V_{LL,\,RMS}$), 50Hz voltage supply with phase sequence of 'abc'. Determine the voltage space vector when the phase-a voltage $v_a(t) = V_m \sin(\omega t) = 200V$. Consider phase-a magnetic axis as the reference.

(2 marks)

Q.6 (b) For the same machine as in Q.6 (a), what would be the 3-phase voltages v_a, v_b and v_c when the voltage space vector is at 90^0 with respect to the phase-a magnetic axis.

(2 marks)

Q.6 (c) Derive the stator voltage equations in 'dq' reference frame for 3-phase permanent magnet synchronous motor (PMSM), starting with voltage equation in space vector (fixed reference frame with phase-a magnetic axis as reference).

(5 marks)

Q.6 (d) Draw the complete control block diagram for stator current controllers for 3-phase PMSM in 'dq' reference frame, clearly explaining the role of each block.

(5 marks)

Q.6 (e) Describe space vector modulation (SVM) scheme in 3-phase switch mode inverters. What are the advantages of SVM over sine pulse width modulation (SPWM) scheme?

(6 marks)

Q.7 A 5 kW/208 V (L-L rms)/50Hz 3-phase squirrel cage induction motor has undergone dc resistance test, no-load test and blocked-rotor test, with the test data given below:

DC resistance test:
Stator resistance $R_{phase\text{-}phase} = 1.1\ \Omega$

No-load test results:
Applied voltage 208V (line-to-line RMS), $I_a = 6.5A$, $P_{no\text{-}load,\ 3\text{-}phase} = 175W$

Blocked-rotor test:
Applied voltage 53V (line-to-line RMS), $I_a = 18.2A$, $P_{blocked,\ 3\text{-}phase} = 900W$

(a) Draw the per-phase equivalent circuit of the induction motor, and indicate what each element represents.

(4 marks)

(b) Estimate the per-phase equivalent circuit parameters for the induction motor.

(6 marks)

END OF PAPER